FAULT LOCATION IN DISTRIBUTION POWER SYSTEMS BY MEANS OF A TOOLBOX BASED ON N-ARY TREE DATA STRUCTURES

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ABSTRACT

The problem of fault location has been studied deeply for transmission lines due its importance in power systems. Nowadays the problem of fault location on distribution systems is receiving special attention mainly because of the power quality regulations.

This paper presents an application software developed in Matlab™ that calculates the location of a fault in a distribution power system, starting from voltages and currents measured at the line terminal and the model of the distribution power system data. The application is based on a N-ary tree structure, which is suitable to be used in this application due to the highly branched and the non-homogeneity nature of the distribution systems.

The application has been developed for all kinds of faults (single-phase, two-phase, two-phase-to-ground, and three-phase faults). Finally, the application of the presented tool to the location of faults is analyzed by using fault data from a real 25 kV distribution line.

INTRODUCTION

Traditionally, fault location techniques have been developed for transmission electric lines due to the importance they have in the electric system and the impact that faults would have on these kinds of lines. More recently, distribution lines have been taken more into account due to the improvement in the quality of power supply derived from operating in a deregulated environment, and the high competition between companies. Due to the growing interest in power quality, power quality monitors that capture power quality phenomena have become an important tool to monitor the quality of the power delivered, so measurements of voltages and currents before and during the fault are easily available and suitable to be used to estimate where the origin of the fault is located.

The faults that these lines experience are caused by short circuits caused by birds and other external objects, insulation breakdown, storms, lightning, etc. This paper focus on faults that cause voltage sags.

Voltage sag is a temporary decrease in the RMS voltage magnitude between 10% and 90% of the declared voltage for durations of one-half cycle to 1 minute [1]. Its frequency of occurrence is between a few tens and several hundreds times per year, its duration of mostly less than 1 s and voltage drops rarely below 40% [2]. It is the most important power quality problem facing many industrial customers since voltage sags are responsible of the shortness of electronic devices life, undesired reset of industrial production lines, among other many harmful effects. Moreover, the causes that produce voltage sags can later produce interruptions if they are not located and cleared.

Most of the current interest in voltage sags is directed to voltage sags due to short-circuit faults, so it is interesting to find where the origin of disturbance sources is located. In literature, different methods for estimating the location of distribution line faults are described. One of these methods uses the fundamental frequency voltages and currents measured at the origin terminal of the line. This method is known as impedance-based method, since it consists of calculating line impedances as seen from the line origin terminal and estimating distances of the faults [2]. Another approach proposed by R. Das uses voltages and currents measured at a line terminal before and during the fault [3]. These methods are based in the knowledge of the network model. Due to the branched nature of distribution networks, presence of laterals, data structures based on N-ary trees are suitable to be used in order to contain all the information about the parameters of the network in a compact way. Moreover, N-ary tree structures allow someone to design software applications for locating faults, by means of algorithms and methods as the ones commented above, in an easy and friendly way.

The paper has been organized as follows. First, a brief description of N-ary trees data structure is presented. Next, the real power system with which the application has been tested is described. Then, the software application is introduced, and performed tests are shown. Finally, conclusions of the work are summarized.

DESCRIPTION OF THE DATA STRUCTURE BASED IN N-ARY TREES

The implementation of the data structure based on N-ary trees has been developed in Matlab™. This structure will contain the information about the topology of the distribution network and the values of its parameters as length, resistance and impedance of its different sections, and the consumptions that are supplied in the different nodes of the network.

As it is described in [4], a tree, T, is a finite set of one or more nodes, such that there is one designated node R, called the root of the tree, and the remaining nodes in (T-{R}) are partitioned into n ≥ 0 disjoint subsets T1, T2, …, Tn, each of which is a tree, and whose roots r1, r2, …, rk, respectively, are children of R. Each node has only one parent. A tree is a data structure used to model data such that related data is in close proximity called branches. A tree can also be used to model hierarchical data. The use of a N-ary tree structure has been motivated by the nature of the distribution networks, because of the presence of laterals and load taps, resulting in a highly branched network. Moreover, there is only one path between one node and its predecessor.
Description of the data structure implementation, as well as the functions that have been implemented starting from this data structure, can be found in [5]. The functions are easily implemented due to recursion, an inherent property of N-ary trees data structures. These functions allow someone to calculate the impedance between two nodes, neglecting the laterals between them, and to implement fault location algorithms such as R. Das method.

POWER DISTRIBUTION SYSTEM

The power distribution system used to test the data structure and its applications is an actual distribution system owned by the power supplier company "ENDESA Distribución Eléctrica SLU". The system has a radial topology and it has a high degree of heterogeneity as a result of the existence of different kind of conductors with different impedance, both overhead and cable lines and lines with different length. There is also heterogeneity in the loads: five transformers feed industrial consumers and eighteen feed household consumers.

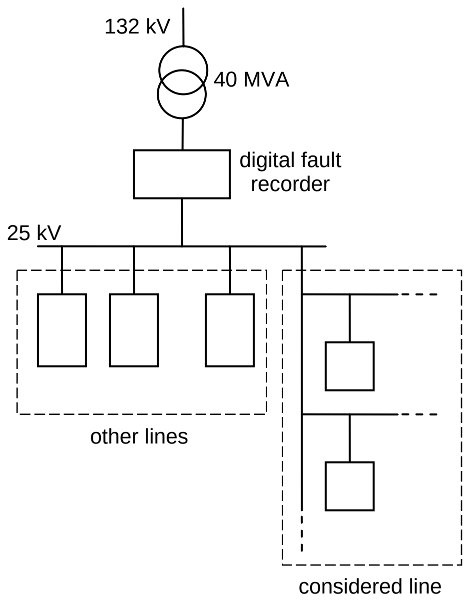

Figure1. Scheme of the power distribution system

One end of the distribution power system is on a medium voltage substation. A 40 MVA apparent power transformer feed several distribution power systems. As it can be seen in Figure 1, the digital fault recorder is at substation level. As it is desired to apply the presented tool by using real recorded faults, the influence of the other present power distribution lines has been taken into account by estimating mean load consumption.

FAULT LOCATION SOFTWARE APPLICATION

The N-ary-tree-based data structure allows storing the distribution line data (topology, conductor parameters, loads, etc.) in such a way that it can be used in an easy and friendly way to make any analysis where only impedances and admittances parameters are involved.
The original data of the available distribution power lines are stored in an access database. First of all, the distribution power line of interest is selected and its information is organized in a N-ary tree data structure.
Figure 2 shows the resulting tree for the considered distribution power line. Each node is identified with an integer and the data structure contains how the nodes are related and the parameters of the different sections (length, resistance and reactance), as well as the consumptions that are connected to the considered line.
Figure 3 shows the results for a real voltage sag. It can be seen the plots corresponding to measured voltages and currents at the substation for the tested case. The voltage sag has several episodes. It starts as single-phase voltage sag, then it evolves to two-phases-to-ground sag, and finally a three-phase sag occurs. Considering the time interval corresponding to the single-phase voltage sag, the location of the fault can be obtained by applying R. Das algorithm [3]. For this kind of fault, an estimation of the location of the fault can be made by comparing the apparent reactance computed by using the faulted phase voltage and current, and the modified reactance of the line between the substation and the location of the fault, with:

$$X_{mr}^{m} = X_{1mr} + \frac{X_{0mr} - X_{1mr}}{3}, \qquad (1)$$

where, $X_{0\mathrm{mr}}$ and $X_{1\mathrm{mr}}$ are the zero and positive sequence reactance of the section.
In this calculation, only impedance parameters are involved so the algorithm is easily automated by using the N-ary tree data structure.
In the example, the faulted-phase voltage and current are needed to be considered in one period, in order to obtain their fundamental frequency components. The shown test was made choosing a period starting at t = 0.14 seconds. The polar plots in Figure 3 correspond to this period.

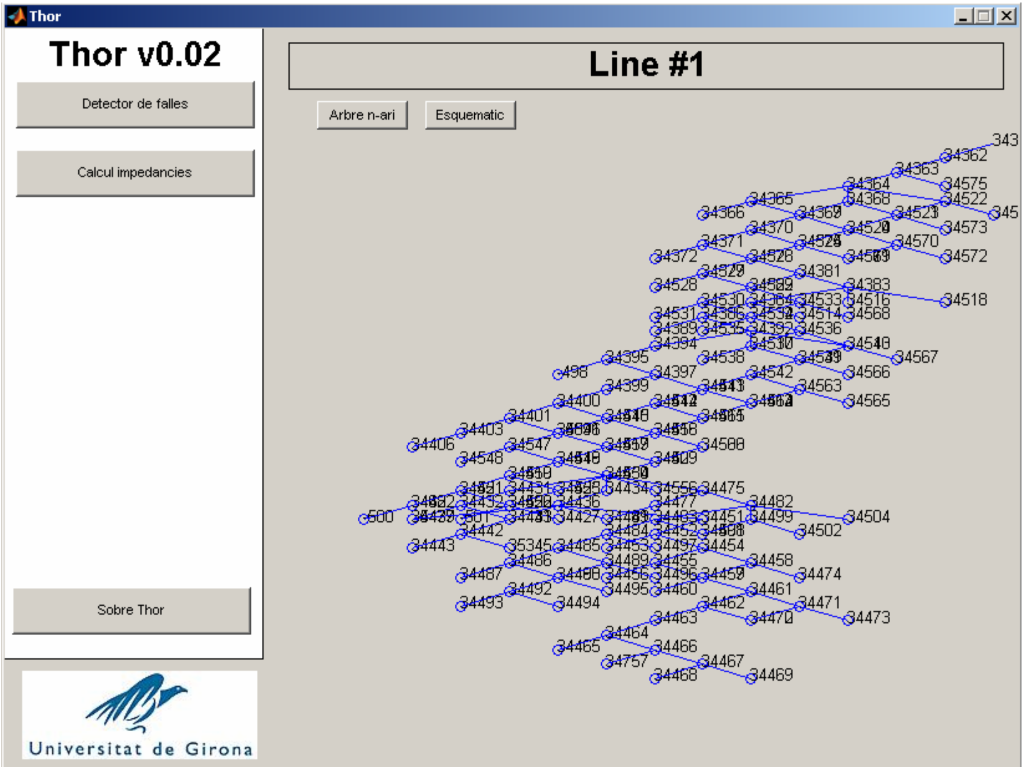

Figure 2. Representation of the considered distribution power line (N-ary tree).

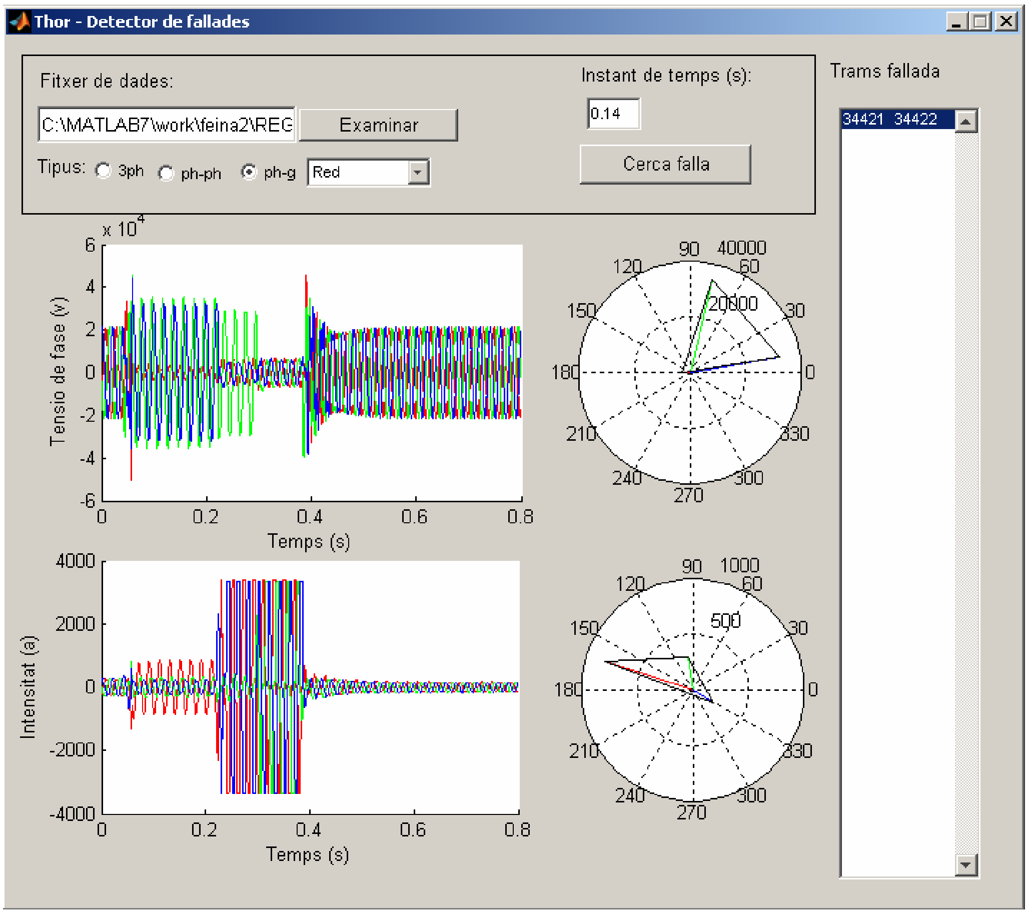

Figure 3. Location of a single-phase voltage sag.

The application of R. Das algorithm results in a location of 4.2 km from the substation, while the data from the distribution utility gives a location of 4 km.
Starting from this example, it can be seen that the presented application allows someone to obtain an estimation of the location of a fault in a easy and fast way. The application is suitable to be used with any distribution power line of ENDESA in the northeast of Spain, and any change in a power line can be easily transferred to the fault location application.

CONCLUSIONS

A software application for fault location in distribution power systems, based on a N-ary tree data structure, is presented. N-ary trees have been used to store information related to the topology and parameters of distribution power systems. These kind of structures are suitable of being used in this application due to the highly branched nature of distribution systems. The use of the recursion, inherent property to N-ary tree structures, allows someone to implement functions involved with the calculation of accumulated magnitudes, such as apparent impedances or lengths, in an easy way.
The used data structure and its derived functions are applied to design a software application for automated fault location starting from the measured voltages and currents at one terminal of the line.

Acknowledgments

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REFERENCES

[1] EN 50160: Voltage characteristics of electricity supplied by public distribution systems
[2] M.H.J. Bollen, 2000, *Understanding Power Quality Problems, Voltage Sags and Interruptions*, John Wiley & Sons, New York, USA.
[3] R. Das, M.S. Sachdev, T.S. Sidhu, "A fault locator for radial subtransmission and distribution lines", *Proceedings 2000 IEEE Power Engineering Society Summer Meeting*, vol. 1, 443 - 448.
[4] B.R. Preiss, 1999, *Data Structures and Algorithms,* John Wiley & Sons, New York, USA.
[5] S. Herraiz, J. Meléndez, G. Ribugent, J. Sánchez, E. Brunet, 2006, "Data structure based on n-ary trees for fault location in distribution networks", *Proceedings 12th International Conference on Harmonics and Quality of Power.*